AP Biology

Unit 2.2 – Material Transport

Notes & Practice Quiz

Contents

Section 1 – Matter & how it Cycles through the environment

1.1 – What materials are essential for organisms?

All life requires essential compounds and about 98% of organism matter is composed of the elements Sulfur, Phosphorous, Oxygen, Nitrogen, Carbon & Hydrogen (SPONCH). Other key elements include ions such as sodium (Na+), chloride (Cl-), calcium (Ca^{2+}), Magnesium (Mg^{2+}) & Iron (Fe^{3+}). The cycling of these materials occurs through feeding and excretion processes within ecosystems. For example autotrophs absorb nitrogen from the soil which was processed by soil bacteria. Herbivores eat plants and are eaten by carnivores; animals then excrete wastes with carbon compounds & nitrogen. **Decomposers** break down dead organisms and return the nutrients to the soil for bacteria to utilize once again.

1.2 – How is carbon cycled through the environment?

Carbon is found in organic forms within the bodies of all organisms. **Cellular respiration** breaks down organic carbon into inorganic carbon dioxide. Autotrophs then use carbon dioxide to convert it back into organic carbon sources during **photosynthesis**. The burning of fossil fuels, utilizing coal and fuels for energy needs and deforestation occur at a much faster pace than the pace at which photosynthesis is occurring, leading to the unfortunate consequence of too much carbon dioxide being released into the atmosphere. Despite some views to the contrary, all the evidence is leading scientists to link this increase with global warming which can have disastrous impacts in the future.

1.3 – Why is carbon the backbone of biological compounds?

Carbon is uniquely suited to form biological molecules because of its bonding capabilities. Carbon can form 4 **covalent bonds** with nearly any other atom, including itself, and the bonds can be single, double or triple. For example, CO_2 looks like O=C=O where carbon has a double bond with each oxygen, giving 4 bonds total that carbon forms. This formation of 4 bonds is called **tetravalence** and while other atoms do have the same ability, carbon is the most stable making it suitable for living tissue. The shapes of carbon molecules can vary widely and grow very large such as hydrocarbons in fuels.

1.4 – What atoms make up the major biomolecules?

Carbohydrates are recognized by their formula: $C_nH_{2n}O_n$, where the amount of carbon and oxygen are about equal and hydrogen is double. **Lipids** have the formula: $C_nH_{2n}O_{<n}$, similar to carbohydrates but the amount of oxygen is much less than carbon. The membrane lipids also contain phosphorous, contributing to its function as discussed in section 3. **Proteins** and **nucleic acids** both contain carbon, oxygen and hydrogen in similar ratios; however, nitrogen is higher in nucleic acids. The atom phosphorous is found in nucleic acids but not proteins and most proteins contain sulfur but nucleic acids do not.

1.5 – How is nitrogen cycled through the environment?

Nitrogen makes up the majority of our atmosphere in the inorganic for N_2, nitrogen gas. The only organisms capable of transforming it into an organic usable form are **nitrogen-fixing bacteria**. These bacteria reside in the soil and many form symbiotic relationships with plants. Once absorbed by plants it becomes part of their body mass available to animals. Animal wastes are high in nitrogen and are released back to the environment as urea, feces or released gases (yes, farts!)

Section 2 – Properties of Water

2.1 – What is the structure of water & how does it behave?

Water is a molecule made of 2 hydrogen atoms connected to 1 oxygen atom. Each hydrogen atom shares its 1 electron with the oxygen and the oxygen shares its 2 electrons with each of the hydrogen atoms, forming two single covalent bonds. The sharing of electrons between the oxygen & hydrogens is not equal however; oxygen pulls the negatively charged electrons towards itself and away from the 2 hydrogen atoms, making the oxygen have a slight negative charge and the hydrogens have a slight positive charge. Because there is a slight negative charge on the oxygen end and slightly positive charges on the hydrogen ends, water behaves like a magnet as is called a **polar molecule** from its **polar covalent bonds**.

2.2 – How do hydrogen bonds result in adhesion & cohesion?

Polarity is the magnetic behavior of a molecule that can result in attractions between molecules. The attractions between hydrogen atoms and other electronegative atoms such as oxygen are called **hydrogen bonds**. **Cohesion** is polarity causing the **same substances** to bond to each other. In water, the positively charged hydrogen atoms of 1 water molecule will attract the negative oxygen atoms of other water molecules. **Adhesion** is polarity causing **different substances** to bond to each other. When water dissolves sugar, the negative oxygen atoms in water bond to the positive hydrogen atoms in sugar. This ability of water to adhere to many substances actually breaks apart the other substance in a process called **dissolving**. Water is the best known solvent on our planet and can dissolve almost any substance, making it extremely important for processes like metabolism. Cohesion & adhesion also give water a high **surface tension**, meaning its surface can withstand a large pressure without breaking.

2.3 – How do hydrogen bonds result in density differences?

Water is very unique in its **density** – how much of a substance fits in a specific volume. Water actually expands as it solidifies as ice, forming a crystal-like structure with a lot of space in between each water molecule. There is so much space between the molecules because the hydrogen bonds between water molecules become fixed into position as they freeze. Liquid water is constantly in motion where the hydrogen bonds constantly break and re-form in different positions, allowing water molecules to be closer to each other. Because liquid water can have its molecules closely packed together it is denser than solid ice, so the ice floats to the surface of the liquid water.

2.4 – How do hydrogen bonds result in its high specific heat?

Because of hydrogen bonds always forming among water molecules, water has a very high **specific heat**, or amount of energy needed to raise its temperature. As surfaces such as skin evaporate water, they require energy to change it to a vapor. This energy is expelled as heat which cools down the organism in a process called **evaporative cooling**. Water environments are very stable because even a large change in air temperature will cause only small changes in a body of water since so many hydrogen bonds keep its liquid form stable.

Section 3 – Water & Cell reactions

3.1 – Why is water important in cell reactions?

A **chemical reaction** is the process in which a molecule changes into a different molecule by forming new bonds. Most of the substances organisms use for energy & use to form structures cannot be changed without some method to make the process easier. Water provides the liquid environment where substances can flow easily and water is also polar, capable of dissolving many substances.

3.2 – How does water react with other substances?

Remember that water is polar and will surround (dissolve) other polar substances. The material that is dissolved is called a **solute** and the substance doing the dissolving is called the **solvent**. Water dissolves other polar substances like sugars & salts so we say these substances are **soluble** and **hydrophilic** (water-loving). Water will not dissolve non-polar substances like fats & waxes so we say these substances are **insoluble** and **hydrophobic** (water-hating). Sometimes water will itself break apart into its atoms or another atom will be added to it when it encounters specific molecules. When a molecule is chemically broken apart by water, this is called a **hydrolysis reaction**. One hydrogen atom (H) will break off of a water molecule and the oxygen & other hydrogen atom (O-H) will be the remaining part. These 2 parts will wedge themselves between the bonds holding together a different molecule and split it apart. In the reverse process called a **dehydration synthesis** reaction, the OH of one molecule and the H of a second molecule will detach and in the process electrons will bond the 2 molecules together. Finally, the H and O-H will bond forming water.

3.3 – How is osmosis related to the 2nd law of thermodynamics?

Because all regions in cells have some amount of water mixed with other solutes, we can refer to the amount of a solute in a given volume of water as the solute **concentration**. Regions where there is more solute/less water than another region are termed **hypertonic**. Regions where there is less solute/more water than another region are termed **hypotonic**. Regions where the solute/ water concentration is equal to another region are termed **isotonic**. Water, like all molecules, tend to spontaneously spread out so they become evenly distributed, termed **down their concentration gradient**. This movement is in accordance with the 2nd law of thermodynamics, increasing disorder or randomness. This general movement of any particle is called **diffusion**, but the movement of water is specifically called **osmosis**, a type of **facilitated diffusion** via channels called **aquaporins**.

3.4 – What is water potential and how is it calculated?

Water potential is a quantifiable value used to predict the direction of osmosis. <u>Water potential is equal to the solute potential plus the pressure potential</u>. The pressure potential will only be a factor if there is an external barrier to exert a force against internal pressure. Only cells will rigid cell walls (all but animals) and containers with sealed lids will have a pressure potential. A blood cell for example is animal-based so there will be no pressure potential, but a plant cell does have a pressure potential. The solute potential is measured by a second equation involving ionization, pressure, temperature & solute concentration. The rule of thumb to remember is that <u>water always moves down its concentration gradient from regions of high WATER concentration/potential (low SOLUTE concentration) to regions of low WATER concentration/potential (high SOLUTE concentration)</u>. If an animal cell with a water potential of -4 is placed into a beaker of pure water with water potential of 0, then water will move from the beaker into the cell, from the higher value of 0 to the lower value of -4. You should remember this example from biology 1 about cells swelling in hypotonic environments, but now you have a means of quantifying it with the water potential formulas. The formulas are on your formula sheet so no need to memorize them but you must memorize the direction of water movement rule.

Section 4 – Membrane Structure & Function

4.1 – What is the function of the cell membrane?

Membranes provide a barrier keeping internal conditions separated from external conditions. In general, **membranes** function in maintaining cell homeostasis by managing what materials move in and out of the cell.

4.2 – What is the composition of the cell membrane?

Membranes are composed of 2 basic parts – phospholipids & proteins. These 2 components make the membrane a fluid structure, capable of shifting its shape and a mosaic of mixed proteins; this is why the currently accepted structure of the membrane is referred to as the **fluid-mosaic model**.

4.3 –What is the structure of a phospholipid?

The **phospholipid** is a polar/hydrophilic phosphate "head" attached to 2 long fatty acid "tails". Draw the phospholipid diagrams (a) & (c) on p. 76. The fatty acid tails can be **saturated** with carbon-carbon single bonds or **unsaturated** with at least one carbon-carbon double bond. This is where the terms saturated & unsaturated fats come from and membranes can also contain saturated and unsaturated fatty acid tails. Unsaturated tails make membranes more fluid, good for keeping membranes from freezing in cold temperatures. Many organisms have adaptations allowing their membrane lipids to change according to temperature for this function. Other lipids in the membrane like **cholesterol** in animals can wedge in between phospholipids to increase fluidity as well.

4.4 – How do phospholipids serve their function?

Because phospholipids have a polar and nonpolar end to them, they tend to group together so that their hydrophobic tails face each other, away from water and then their hydrophilic heads face water. These associations result in a **phospholipid bilayer**. Draw figure 5.13 on p.77 to illustrate this. The membrane is **selectively permeable** towards materials based on its lipids & proteins.

4.5 – What are the characteristics of transmembrane proteins?

Proteins come in a variety of shapes and sizes due to their very complex amino acid monomers & folding processes. The structure of a protein will always match its function, as with all molecules in biology. Proteins serving as channels for moving molecules through the membrane must span the membrane from the inside to the outside. This means the regions contacting water/cytoplasm are made of hydrophilic amino acids and the regions contacting the fatty acid tails are made of hydrophobic amino acids. Draw figure 7.9 on p.129 to illustrate this, labeling the hydrophobic regions and the hydrophilic regions. Any protein that spans the membrane is called a **transmembrane protein or integral protein** and is usually associated with material transport.

4.6 – What are the functions of membrane proteins?

Besides channel proteins many proteins serve to connect cells together such as **plasmodesmata**, **desmosomes**, **tight junctions** and **gap junctions**. Some proteins are enzymes converting one molecule into another molecule like ATP synthase and special enzymes used in cell signaling to be discussed in unit 3. Cell recognition proteins have specific attached molecules like carbohydrates serving as ID tags for your cells being able to recognize each other as safe instead of foreign tissue to be destroyed. A final protein type of importance is those acting as molecule receptors during the process of cell signaling. Receptor proteins can receive chemical stimuli and cause a cellular response, critical to homeostasis.

Section 5 – Transport across membranes

5.1 – How does a membrane establish concentration gradients?

A **concentration gradient** refers to the relative concentration of a substance on both sides of a membrane. Membranes are selectively permeable for certain substances so some materials can cross and others cannot. Materials that cannot cross the membrane can create a gradient by building up in the region they are essentially stuck in.

5.2 – What forms of Passive Transport do molecules use?

Passive transport is the movement of a substance across a membrane from areas it is highly concentrated to areas of lower concentration (down its concentration gradient). This requires no cell energy and actually releases energy in some cases. **Diffusion** and **osmosis** were discussed in section 3, review them if needed. Another passive transport type is called **facilitated diffusion**. This involves the diffusion of a material through a protein channel. Any molecule that is polar or charged that would be repelled by the lipid bilayer can move by facilitated diffusion if a channel protein exists for it. Some examples include Na+, Cl-, K+ (salts), small sugars like glucose, amino acids and even water are polar so must move through protein channels via facilitated diffusion. Small enough molecules like CO_2 & O_2 can cross directly through the bilayer but always down their concentration gradient. Nonpolar molecules like fats & other lipids cross the lipid bilayer as well.

5.3 – What forms of active transport do small molecules use?

Active transport is the movement of a substance across a membrane from areas it is *unconcentrated* to areas of higher concentration (against its concentration gradient). This requires cell energy, usually ATP but sometimes can use oxidation methods like in photosynthesis or respiration. The **proton pumps** in those processes are a prime example of active transport. Another classic example is the **sodium/potassium pump** in nerve cells. We will discuss the mechanism in detail later but an overview is that ATP is used to actively pump the positive sodium ions out of the cell, keeping the inside of nerve cells usually negative. Another type of active transport is called **cotransport**. As the name implies, 2 substances move together in a way. The sucrose transporter is an example where ATP powers a proton pump, creating a proton gradient. The protons can then diffuse back across the membrane down their concentration gradient, very similar to the ATP synthase example. However, instead of ATP being made, a molecule of sucrose can bind to a transport protein when activated by a proton. Once the proton & sucrose are bound, the transport protein moves the proton down its concentration gradient but sucrose is moved against its concentration gradient. This mechanism is essential to plants and animals forming reserves of carbohydrates in specialized storage cells like the liver & starch granules.

5.4 – How else is the membrane used in active transport?

The membrane itself can participate in transporting substance by fusing with substance and folding inwards or outwards. When substances bind to a receptor on the exterior surface of a cell, **receptor-mediated endocytosis** occurs, causing the membrane to fold inwards creating a vesicle that pinches off inside the cell. Two other forms of **endocytosis** are termed **phagocytosis** ("eating") and **pinocytosis** ("drinking"). Draw figure 7.22 on p.139 for reference. **Exocytosis** is when the cell excretes materials out of the cell. Draw figure 7.12 on p.131 for reference. Both exocytosis & endocytosis involve a mass reconfiguration of the membrane and require ATP although the mechanisms for this are rarely shown on diagrams. They are both processes crucial to pathogen destruction, membrane formation, information transfer & material transfer.

Quiz Practice

A July 2015 publication in the *Journal of Thoracic Cancer* investigated the use of a medicine called Bortezomib in treating thyroid cancer. About 70% of patients with thyroid cancer can be treated with ^{131}I which is a radioactive form of iodine that kills cells with its radioactivity. In the other 30% of patients this treatment is ineffective since their cancer cells are unable to uptake Iodine. Bortezomib was tested in this 30% subgroup for effectiveness of improving Iodine uptake.

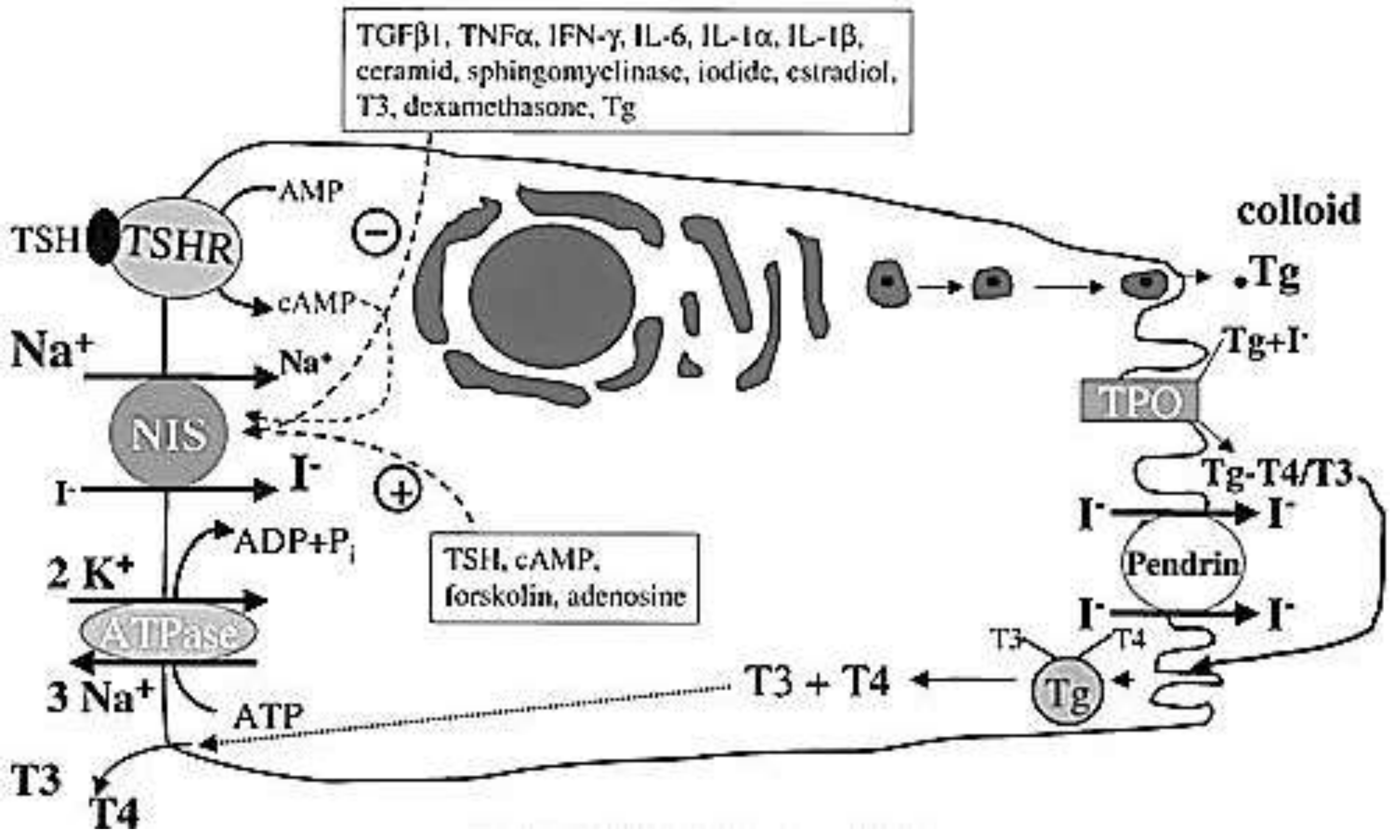

Figure 1: Movement of materials in a thyroid cell. Arrows indicate direction of substance movement. The size of the text for substances symbolizes its relative concentration gradient from one side of the cell to the other.

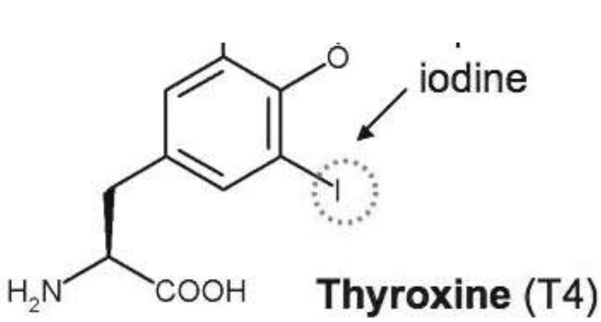

Figure 2: Partial molecular structure of T4

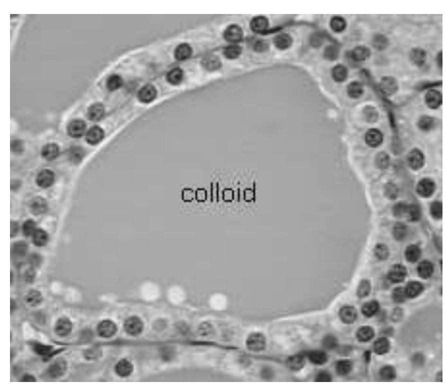

Figure 3: Thyroid cells forming a circular arrangement around a fluid of Tg and water.

1. Based on Figure 1, **explain** how Iodine (I^-) moves into the cell. Be sure to include the type of transport and the energy requirements.

2. Based on Figure 1, **explain** how Potassium (K^+) moves into the cell. Be sure to include the type of transport and the energy requirements.

3. Based on figure 1, **describe** the likely molecular characteristics of the Tg molecule and **justify** your response. Note, the Tg molecule is represented by a black dot in some parts of the diagram.

4. Based on figure 1, **describe** the likely molecular characteristics of the T3 molecule and **justify** your response.

5. The Pressure potential of the colloid region is 0, The concentration is 0.3M, temperature is 25°C, and the water potential for the thyroid cells is -4. **Explain** where the net flow of water will be. Assume that Tg does not ionize (dissolve) in water.

6. Tg does not ionize (dissolve) in water but NaCl ionizes into Na+ and Cl- allowing it to dissolve in water. **Identify** one other substance in figure 1 that would dissolve in water. **Draw** a diagram below to show how the water molecules would orient themselves around this substance.

7. Figure 2 shows the structure of a thyroid hormone called T4. **Identify** 1 nutrient cycle that would be impacted by an increase in T4 and **describe** how 1 organism besides humans would be impacted.